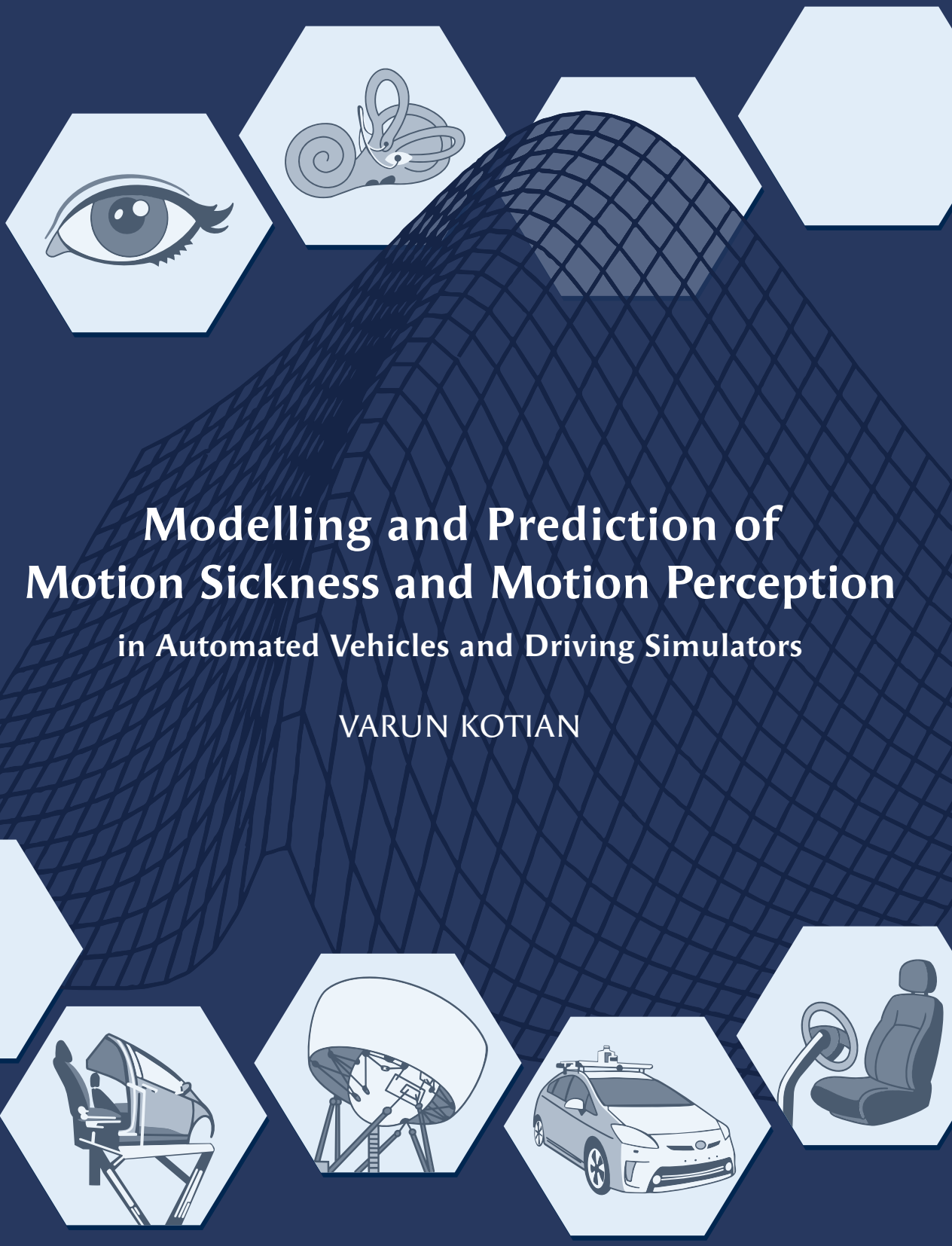

Modelling and Prediction of Motion Sickness and Motion Perception

in Automated Vehicles and Driving Simulators

VARUN KOTIAN

Motion Perception and Sickness Modelling and Prediction

for Automated Driving and Simulators

Doctoral Dissertation

by

Varun Kotian

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Motion Perception and Sickness Modelling and Prediction

for Automated Driving and Simulators

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Technische Universiteit Eindhoven,
op gezag van de rector magnificus prof. dr. ir. S. Lenaerts,
voor een commissie aangewezen door het College voor Promoties,
in hetopenbaar te verdedigen op dinsdag 12 november 2026 om 11:00 uur

door

Varun Kotian

geborn te Mumbai, India.

Dit proefschrift is goedgekeurd door de promotoren en de samenstelling van de promotiecommissie is als volgt:

Voorzitter	prof.dr.ir X. YYYY
1e Promotor	prof.dr.ir X. YYYY
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	prof.dr.ir X. YYYY (University of ZZZZ)
Adviseur	prof.dr.ir X. YYYY (University of ZZZZ)

Het onderzoek dat in dit proefschrift wordt beschreven is uitgevoerd in overeenstemming met de TU/e Gedragscode Wetenschapsbeoefening.

Knowledge and awareness are vague, and perhaps better called illusions.
Everyone lives within their own subjective interpretation.

Itachi Uchiha

Contents

Summary

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

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1

Introduction

You have control over action alone, never over its results.
Therefore, begin your work without attachment.

Bhagavad Gita, 2.47

1

1.1 Background

1.2 Objectives

2

Amplitude and Temporal Dynamics of Motion Sickness

Life is really simple, but we insist on making it complicated

Confucius

This chapter is based on *Irmak, T., Kotian, V., Happee, R., de Winkel, K. N., & Pool, D. M. (2022). Amplitude and Temporal Dynamics of Motion Sickness. Frontiers in Systems Neuroscience, 16.*

The appendices for this chapter can be found at Appendix A.

Abstract

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2.1 Introduction

2.2 Methods

2.3 Results

2.4 Discussion

2.5 Conclusion

3

The Role of Vision in Sensory Integration Models for Predicting Motion Perception and Sickness

Everything we hear is an opinion, not a fact.
Everything we see is a perspective, not the truth.

Marcus Aurelius

This chapter is based on *Kotian, V., Irmak, T., Pool, D., & Happee, R. (2024). The role of vision in sensory integration models for predicting motion perception and sickness. Experimental Brain Research, 242(3), 685–725.*
The appendices for this chapter can be found at Appendix B.

Abstract

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3.1 Introduction

3.2 Methods

3.3 Results

3.4 Discussion

3.5 Conclusion

4

Personalising Motion Sickness Models: Estimation and Distribution of Individual-Specific Parameters

Are all human beings truly equal?

Kiyotaka Ayanokoji

This chapter is based on *Kotian, V., Pool, D. M., & Happee, R. (2025). Personalising Motion Sickness Models: Estimation and Statistical Modeling of Individual-Specific Parameters. Frontiers in Systems Neuroscience, 19, 1531795.* and *Kotian, V., Pool, D. M., & Happee, R. (2023). Modelling individual motion sickness accumulation in vehicles and driving simulators. Proceedings of the Driving Simulation Conference, Antibes, France.*

The appendices for this chapter can be found at Appendix C.

Abstract

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4.1 Introduction

4.2 Methods

4.3 Results

4.4 Discussion

4.5 Conclusion

5

Impact of Physical and Visual Motion on Subjective Perception of Vertical Orientation

Whatever happens, happens

Spike Spiegel

This chapter is based on *Kotian, V., Pool, D. M., Happee, R., Li, S. & Wada, T. (2025). Impact of Physical and Visual Motion on Subjective Perception of Vertical Orientation. Research Square preprint.*

The appendices for this chapter can be found at Appendix D.

Abstract

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5.1 Introduction

5.2 Methods

5.3 Results

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6

Discussion

In the end, it's not the outcome that defines us, but how we faced it.

Erwin Smith

This chapter summarises the main findings of this thesis and their implications, and presents the main recommendations for future work.

Bibliography

A

Appendix for Chapter 2

B

Appendix for Chapter 3

C

Appendix for Chapter 4

D

Appendix for Chapter 5

About the Author

Varun Kotian was born in Mumbai, India. He began his PhD in 2021 at Delft University of Technology at the Department of Cognitive Robotics within the Faculty of Mechanical Engineering. His research is funded by Toyota Motor Europe and focuses on developing models for predicting motion sickness in automated driving and driving simulators.

Prior to his PhD research, Varun earned his master's in Vehicle Engineering from Delft University of Technology. His master's thesis, titled 'Amplitude Dynamics of Motion Sickness', laid the foundation for his PhD research. His background through his bachelor's degree in Mechanical Engineering from K. J. Somaiya College of Engineering has helped throughout his research.

Varun Kotian is not only a curious researcher, but also an avid traveller who enjoys hiking and snowboarding.

List of Publications

14. **Kotian, V.***, Jain, V.*, Lazcano A. M. R., Pool, D. M., Happee, R., & Shyrokau, B. (2025). Reducing Discomfort in Driving Simulators: Motion Cueing for Motion Sickness Mitigation. *TechRxiv preprint.* (Chapter 6)
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6. **Kotian, V.**, Irmak, T., Pool, D., & Happee, R. (2024). The role of vision in sensory integration models for predicting motion perception and sickness. *Experimental Brain Research*, 242(3), 685–725. (Chapter 3)
5. **Kotian, V.**, Pool, D. M., & Happee, R. (2023). Modelling individual motion sickness accumulation in vehicles and driving simulators. *Proceedings of the Driving Simulation Conference*, Antibes, France. (preliminary version of Chapter 4)
4. Papaioannou, G., Cvetkovic, M., Messiou, C., **Kotian, V.**, Shyrokau, B., & Happee, R. (2023). A novel experiment to unravel fundamental questions about postural stability and motion comfort in automated vehicles. *Proceedings of the 4th International Comfort Congress*, 123–126.
3. Happee, R., **Kotian, V.**, & de Winkel, K. (2023). Neck stabilization through sensory integration of vestibular and visual motion cues. *Frontiers in Neurology*, 14, 1266345.
2. De Winkel, K. N., Irmak, T., **Kotian, V.**, Pool, D. M., & Happee, R. (2022). Relating individual motion sickness levels to subjective discomfort ratings. *Experimental Brain Research*, 2022, 1, 1–10.
1. Irmak, T.*, **Kotian, V.***, Happee, R., de Winkel, K. N., & Pool, D. M. (2022). Amplitude and Temporal Dynamics of Motion Sickness. *Frontiers in Systems Neuroscience*, 16. (Chapter 2)

Included in this thesis.

* Contributed equally

Patents

1. Motion Cueing Algorithm for Motion Sickness Mitigation in Driving Simulators (2025).
2. Personalized motion sickness modelling and predictive mitigation in automated driving and simulation environments (2025).

Acknowledgments

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Varun Kotian
Delft, October 2025

Propositions

accompanying the dissertation

Motion Perception and Sickness Modelling and Prediction

for Automated Driving and Simulators

by

Varun Kotian

1. Individual variability in motion sickness development can be captured with only a personalised accumulation model.
   This proposition pertains to Chapter 2.
2. Lorem ipsum dolor sit amet, consectetuer adipiscing elit.
   This proposition pertains to Chapters 3 and 5.
3. Lorem ipsum dolor sit amet, consectetuer adipiscing elit.
   This proposition pertains to Chapters 2.
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   This proposition pertains to Chapters 4.
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7. Lorem ipsum dolor sit amet, consectetuer adipiscing elit.
8. GenAI replaces mundane work while amplifying the need for human experts.
9. The selfish intent of wanting peace initiates wars.

These propositions are regarded as opposable and defendable, and have been approved as such by the promotor Prof. Dr. Ir. R. Happee, and co-promotor, Dr. Ir. D. M. Pool.

Can we prevent motion sickness in the age of automated driving?

As automated vehicles position drivers as passive passengers and simulators become increasingly immersive, motion sickness has emerged as a critical barrier to user acceptance. Traditional models rely on group averages and focus on extreme outcomes, failing to capture the subtle, individual discomforts like nausea and dizziness that ruin the passenger experience.

This book presents a framework for predicting and mitigating motion sickness at the individual level by moving beyond a one-size-fits-all approach. The research introduces a personalized modeling method that adapts to specific user sensitivities using two key parameters and proposes critical updates to sensory conflict models to better align visual perception with reality. These culminate in a novel control algorithm for simulators that reduces motion sickness by over 50% without sacrificing realism. This work aims to bridge the gap between biological variability and mechanical design to create a more comfortable experience.

TU Delft